Guideline for Earthing of Buildings and Industrial plants

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Paneendra Kumar Bl
VKES.org

TRAINING IN ELECTRICAL ENGINEERING

Guideline for Earthing of Buildings and Industrial Plants

VKES

VIDYUTH KANTI ENGINEERING SERVICES

Contents

No 213, 13th Main RBI Layout JP Nagar 7th Phase, Bangalore 560078. Mobile: 91-9880784082,
Email: vkes@vkes.org, vkes765@gmail.com, www.vkes.org

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Email: vkes@vkes.org, vkes765@gmail.com, www.vkes.org

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Guideline for Earthing of Buildings and Industrial plants

1.0 Scope

This guide covers the earthing of Domestic, Commercial buildings and Industrial Plants. These can be constructed by concrete or steel frame or both. The industrial plants means outdoor areas in Industries like refinery, power plant, Cement plant, steel plant etc.

2.0 Exclusions

Substation, Generator neutral, Transmission line, Telecommunication facility, Hospital, Mines, Offshore, Ships, Portable equipment internal earthing, Data centre, DC system earthing, NGR NGT sizing, Lightning protection system design, static charges protection and EMC protection.

3.0 Reference Standard

This guide is prepared after referring to the following standards: BS 7430, IEEE 142, EN 50522 and IS 3043. Readers should note that this guide is supplementary to these standards. Readers have to refer the standards before designing a system.

4.0 What is the function of earthing

Basically earthing is done to protect Human beings from getting electrocuted and to protect Overvoltage in Electrical equipment, which may lead to insulation failure.

5.0 What is the difference between Earthing of Substation and Building

In order to protect people, the current through human body has to be kept lower than certain values. Current through the body depends on the voltage across the body and the body resistance. In case of substation Earthing design, the voltage seen by the body is calculated and compared with tolerable values. Whereas in the earthing design of building and industries touch and step voltage calculation are not carried out. The total earth grid resistance has to be maintained below certain prescribed value and earth loop impedance has to be kept low. In a substation the human beings working are electrical professional, they are trained people or they are supervised by someone. In industries also there are trained people but in case of domestic and commercial buildings, non electrical non supervised person may get electrocuted. In a substation the rise in ground potential is due to the flow of part of fault current through the earth and earth grid. In buildings and industries the rise in potential is due to the flow of a part of the fault current through the earth (major part of fault current flows through earth loop impedance).

6.0 Basic requirement before starting the earthing design

Before stating the design the designer should have the following details:
Earth resistivity of the site (CL 19.0)
Fault current calculation results (CL 9.0)
Details about the regulation
Select the material of earthing conductor (CL 14.0)
Earthing conductor Sizing (Refer CL 10.0)
Layout of the industry/Site/Plant, (Refer CL 23.0)
Type of source earthing to be used (Refer CL 17.0)
Resistance of earthing system to be achieved (CL 24.0)

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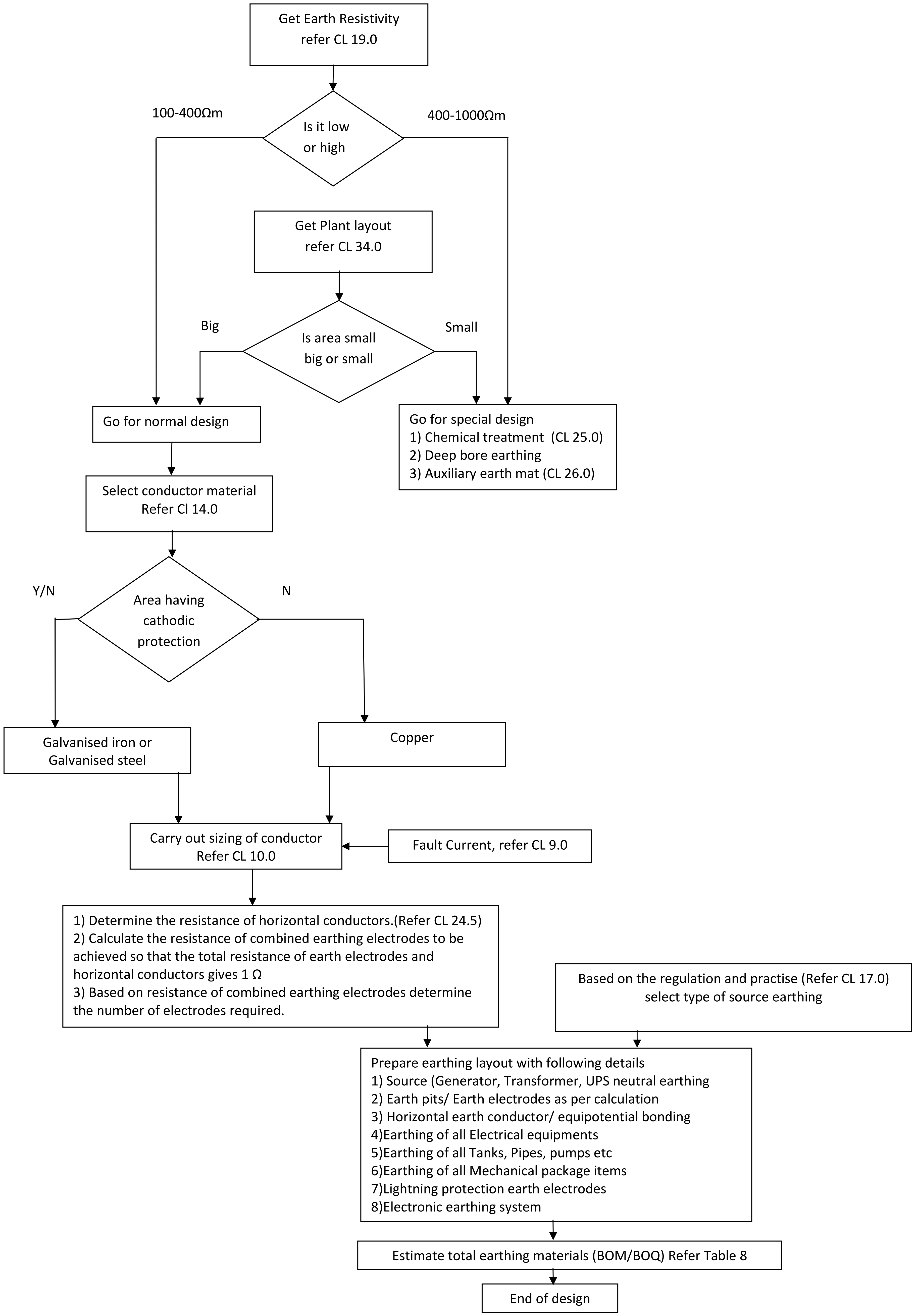
7.0 Methodology of earthing design

Users can refer the below flowchart which will guide on how to proceed with the design



8.0 Objective of earthing design

The Objective of earthing design is to carry out the following

- Sizing of earthing conductors (Refer CL 10.0)
- Earthing system resistance calculation and determine number of vertical driven earth rods required (Refer CL 24.0)
- Preparation of earthing layout (Refer CL 27.0)
- Estimation of total quantity of earthing materials. Prepare Bill of material BOM or Bill of Quantity BOQ (Refer Table 8)

9.0 Fault current calculation results

Earth Fault current is calculated using standard IEC 909 either manually or using a computer program. The result of the calculation which is the initial symmetrical short circuit current using the sub transient reactance of generators is used in the earthing.

10.0 Material of earthing conductor

Earthing Conductor material can be copper, aluminium or steel . The choice of material depends on the owner's specification, type of site etc. In places where cathodic protection is carried out, avoid using copper. Aluminium also should be avoided, as it is more prone to corrosions. Galvanised iron or galvanised steel is a good choice since buried pipelines and building structures are also steel. This combination will not cause corrosion due to dissimilar metals. Vertical driven rods and horizontal strip should be of same material. Refer CL 34.1 Table 9 for various materials that can be used.

11.0 Earthing conductor sizing

$S = \frac{I\sqrt{t}}{k}$ (BS 7430 - CL 9.7),

I is fault current in A rms, and t fault duration in sec, S is in mm^2

Type of location/ Installation	Time t,(sec)	Initial Temperature T_1 ^oC	Final Temperature T_2, ^oC	copper	steel	Al
					k	
Conductor in Hazardous area (Temperature class T3)	1	40	200	149	55.5	101
Conductor touching cables	1	40	250	165	61.6	112
Conductor inside multicore cable	1	90	250	140	51.5	94
Conductor not touching cables (Note1)	1	40	395(cu) 325(Al) 500(steel)	201	80.5	125

Table 1

For copper K varies from 150 to 250, for steel it can vary from 50 to 90, for exact values use below formula (BS 7430) to calculate. Conductor sizing depends on the initial temperature and final temperature upto which it can be allowed.

$$k = K\sqrt{\ln\left(\frac{T_2+\beta}{T_1+\beta}\right)}$$

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	K	β
Copper	226	254
Aluminium	148	228
Steel	78	202

Table 2

The duration t can be 1 sec or 3 sec. It depends on owners specification or regulations.

Bolting joint is not effective above 200^oC temperature. Above 250^oC nearby XLPE insulated cables get affected. From 200^oC to 250^oC peeling of galvanised layer will occur. Hence It is better to restrict the maximum temperature to 200^oC and below.

Note 1: Bare conductors can be subjected to much high temperatures. But there can be no ideal bare conductor. At some location or other, earthing conductor will touch cables, for example in cable tray. Hence exercise caution before selecting these factors.

EN 50522 provides an equation to computer cross section of conductor similar to BS7430

$$A = \frac{I}{k}\sqrt{\frac{t}{\ln\frac{T_2+\beta}{T_1+\beta}}}$$

k is 226 for Cu, 78 for steel

β is reciprocal of temperature coefficient of resistance at $0^{\circ}\mathrm{C}$, 234.4 for Cu, 202 for steel

12.0 Current density limitation at electrode

As current density at the electrode increases, heat dissipation increases. The moisture in soil evaporates. The resistance of the electrode increases. The conduction in soil is electrolytic and due to moisture. At some point where there is no moisture the resistance becomes infinite and earthing system fails at that stage. Hence the current density of an electrode should not increase beyond a certain point which leads to rapid evaporation of moisture.

J $=10^3\sqrt{\frac{57.7}{\rho t}}$ (J is in A/m^2) (BS 7430 CL 9.8, IS 3043)

for a 200 Ωm soil, fault of 1 sec, current density should be limited to 537 A/m^2 per electrode.

$\mathrm{I} = \frac{1140 \text{ x d}}{\sqrt{\rho \text{ x t}}}$ (IEEE 142 CL 4.1.6)

I current in A/m, d is rod dia in mm, ρ resistivity in ohm-cm

For 3m, 50mm dia and ρ of 20000 ohm cm,

$\mathrm{I} = \frac{1140 \text{ x } 50}{\sqrt{20000 \text{ x1}}}$ = 403A/m, ie 1209A per electrode.

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13.0 Minimum dimensions of conductors

The minimum size is based on mechanical strength and corrosion. (Table 3)

	Galvanised steel	Copper
Strip	90 mm^2	50 mm^2
Pipe	25 mm OD	20 mm OD
Rod	16 mm OD	
Wire	10 mm OD	25 mm^2

14.0 Corrosion

Earthing conductor being buried in a soil consisting of moisture and salt is bound to undergo corrosion. We cannot stop corrosion. But we have to select a conductor material which undergoes less corrosion. Further the size of the conductor should take care of reduction in size over a period of time due to corrosion. Some margin has to be taken while sizing the earthing conductor. Some owners use insulated cable to connect the external metal surfaces to the underground earthing system. Care should be taken so that Earthing conductor does not increase the corrosion of other metals in the plant.

Where resistivity is 25-100 Ωm oversize the conductor by 15%, below 25 Ωm oversize the conductor by 30%.Lower the resistivity higher the salt content and more is the corrosion. Whenever the resistivity is very low the over sizing factor has to be higher.

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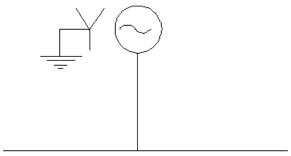
15.0 Source earthing

Source earthing means earthing of the power source like Industrial generator neutral or transformer neutral. As per BS 7430 the guideline for earthing of generator is based on the size of the generator. As per IEEE 142 the guideline for earthing of neutral is based on number of generators and whether the generator is parallel with the grid or not. Users have to refer the standards as well as local regulations before deciding on the type of earthing of generator. Utility generator earthing is not covered in this guideline. The source earthing has several classification based on the resistance refer CL 17.0 for more details.

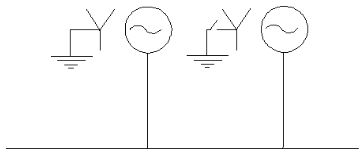
15.1 One Generator in isolation

The generator can be 415V or 11kV it can be solidly earthed without resistance.



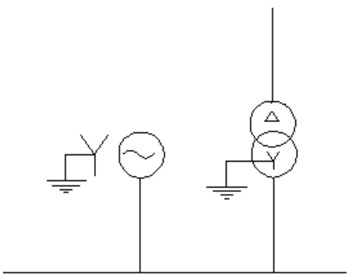
15.2 Many Generator in isolation

The generator can be 415V or 11kV it can be solidly earthed without resistance. Normal practise is to earth only one generator to prevent circulating currents.



15.3 One Generator parallel with utility

The generator can be 415V or 11kV it can be solidly earthed without resistance.

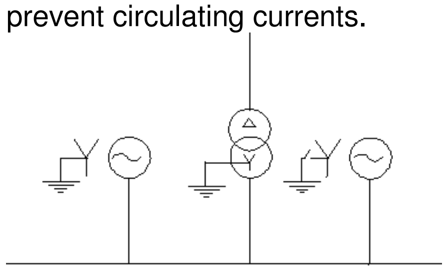


paralleing will be momentary

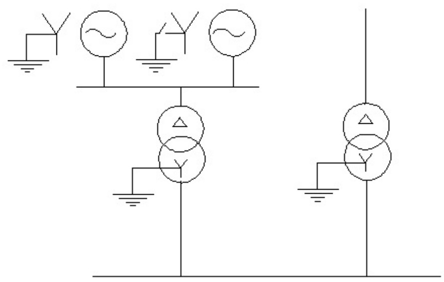
if parallel continuously Neutral should have isolator

15.4 Many Generator parallel with utility

The generator can be 415V or 11kV it can be solidly earthed without resistance. Normal practise is to earth only one generator to prevent circulating currents.

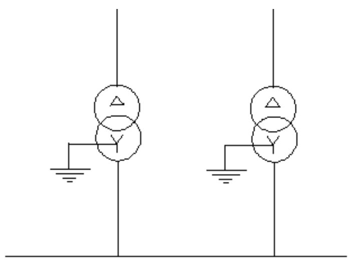


paralleing will be momentary



Continuous paralleling

15.5 Many Transformers



Can be paralled Continuously

Paralleling of generators with neutral closed causes circulating currents with third harmonics. More details about this are covered in separate guideline related to generator earthing.

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15.6 Transformer neutral earthing

Neutral at the Secondary of the Transformer with star winding are earthed either with a resistance or solidly earthed depending on the type of earthing system as given in CL 17.0

15.7 Earthing of UPS neutral

If neutral in the star winding of the UPS output transformer is not earthed, then it will be difficult to detect a single line to ground fault, it will lead to over voltages. Hence it is recommended to earth the neutral of UPS also. UPS vendor and Control system equipment vendor should be consulted at the initial stage of engineering to decide on the type of earthing of UPS neutral.

16.0 Types of earthing based on resistance

The neutral can be earthed either by inserting a resistor or without a resistor between the neutral and the earth electrode. The different types of earthing based on this connection are: Solidly grounded system, Unearthed or ungrounded system, Resistance earthed system.

16.1 Solidly grounded system

There is no intentional resistor introduced between the neutral/ star point of the transformer/generator and the earth electrode. The single line to ground fault current will be high in this system. Hence detecting the fault is not difficult. There will be no transient overvoltage. Hence higher insulation need not be used. Most of the Transmission and distribution system are solidly grounded.

16.2 Unearthed or ungrounded system

There is no connection between the neutral/star point of the transformer/generator and the earth electrode. The single line to ground fault current will be very low. Hence detecting the fault is very difficult. There will be high transient overvoltage. Hence higher insulation needs to be used. This system is very rarely used except in some system like hospitals.

16.3 Reactance earthed system and resonant earthed system

This is not covered in this guideline as this earthing system is used less frequently. Readers can refer the standards for more details.

16.4 Resistance earthed system

A resistor is introduced between the neutral/star point of the transformer/generator and the earth electrode. The resistor is called NGR – neutral grounding resistor. If used along with a transformer it is called NGT Neutral grounding transformer. When the voltage is high a NGT along with NGR is used. The single line to ground fault current will be limited in this system. Hence detecting fault need sensitive relays. However there will be no transient overvoltage. Hence higher insulation need not be used. The advantage of limiting the fault current is that there will be no welding of stampings of motors during a fault. Hence this system is very common in industries having 3.3kV, 6.6kV or 11kV motors. The advantage is that the system can continue to operate even if there is a fault. But fault need to be isolated or else a second ground fault will lead to line to line fault.

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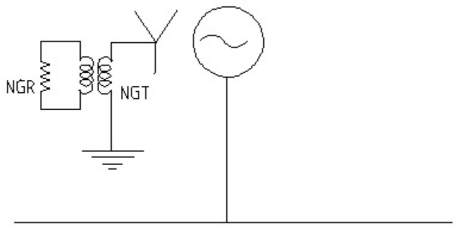
16.5 Types of Resistance earthed system

Resistance grounding has two types one is high resistance grounding and other is low resistance grounding. High resistance grounding is used at Power generating station generators. NGR and NGT are used in high resistance grounding. Low resistance grounding is used at Medium voltage distribution system transformers star point to limit the fault current in 3.3kV 6.6kV or 11kV Motors. Only NGR is used in low resistance grounding. Sizing of NGR and NGT is covered in separate design guide.



NGT (Neutral Grounding Transformer)
NGR (Neutral Grounding Resistor)

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17.0 Different types of LV earthing system (BS 7430)

Before beginning the LV system earthing, first check type of system to be used. Is it TN-S, TN-C, TN-CS, TT, IT. Selection of the type depends on local regulations.

Source	Load		
T	T		✓
T	N	C/S	✓
~~T~~	~~I~~		X
~~N~~	~~T~~		X
~~N~~	~~N~~		X
~~N~~	~~I~~		X
I	T		✓
~~I~~	~~N~~		X
~~I~~	~~I~~		X

Table 4

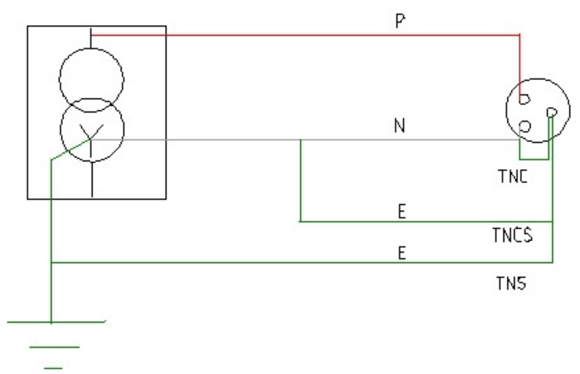
Source side earthing type can be T or I

T : effectively earthed , I : un earthed.

Load side earthing can be T or N

T : load side has own earthing terminal or earth electrode,

N: Load side earthing system connected to source side earthing

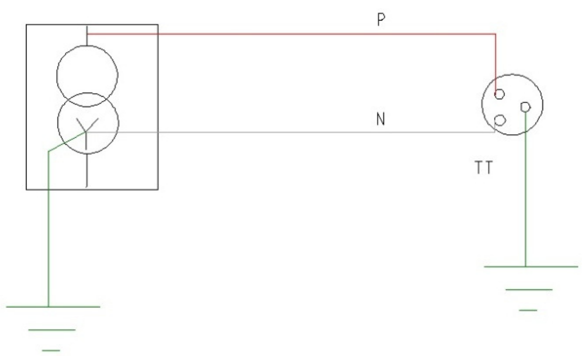


TN system has three variations.

TNC- Protective earth (PE) and Neutral are combined

TNS- Protective earth (PE) and Neutral are Separating

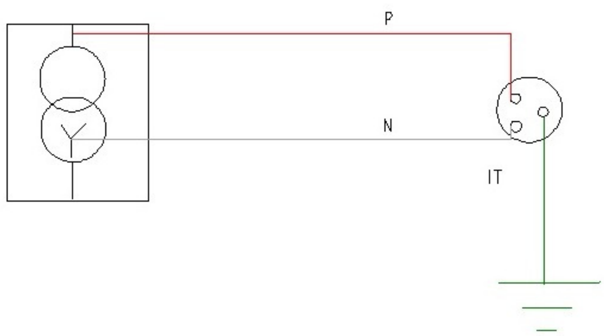
TNCS- combination of TNC upto some point from the source and TNS after some point upto the load



TT system

There is no Protective earth (PE) conductor from source to load

Earthing at source and load are independent. Fault current flow through the earth



IT system

There is no Protective earth (PE) conductor from source to load. The source is unearthed

Load side is provided with an independent earthing.

Fault current flow through the earth and returns to the neutral via coupling capacitor.

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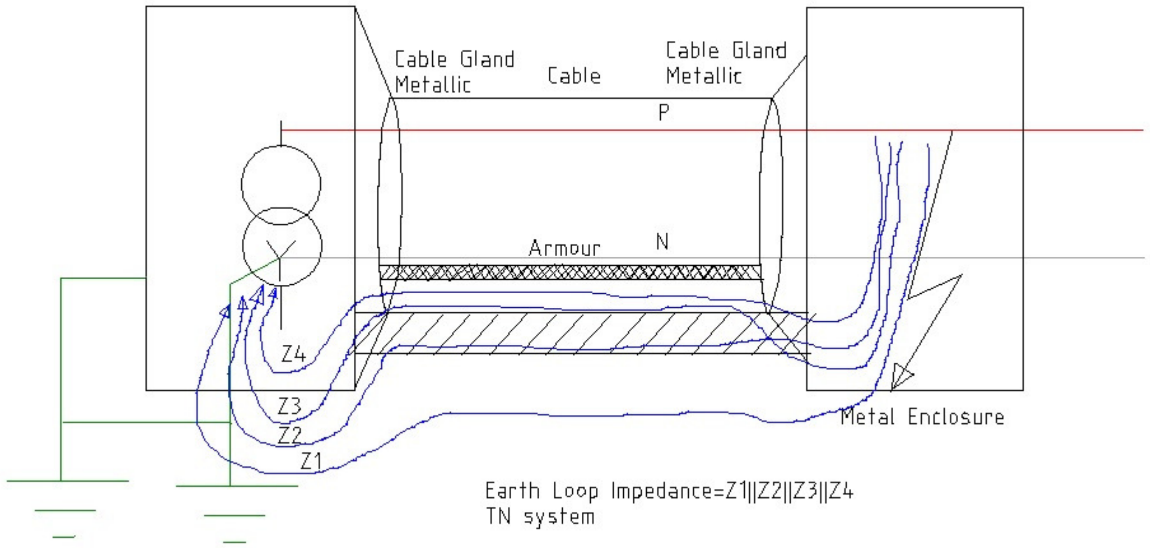
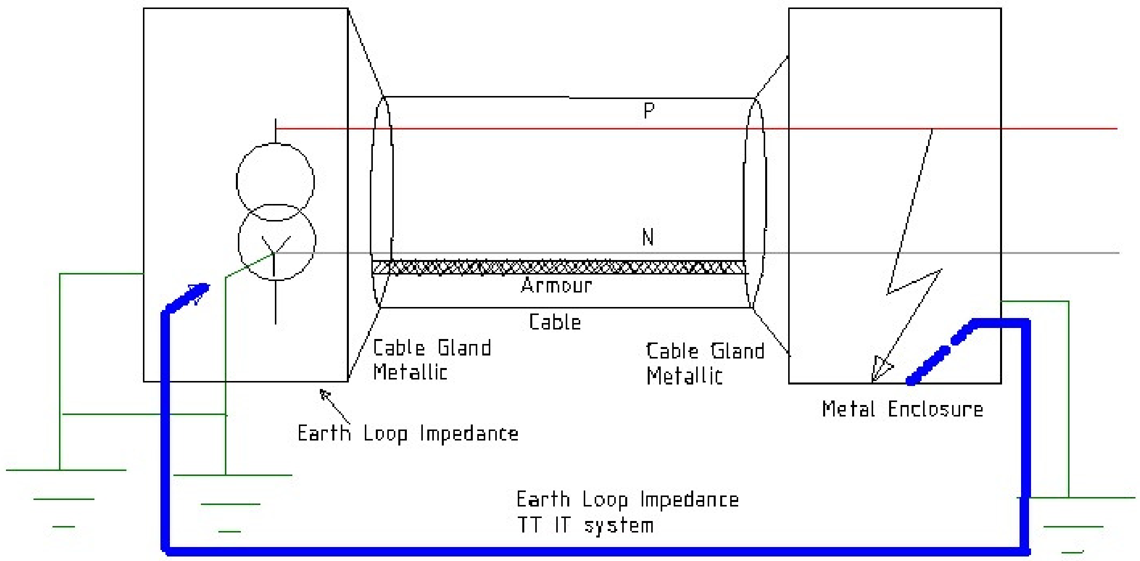
17.1 Earth Loop Impedance

This is the impedance seen by the fault current from the fault location upto the neutral point of the source where the current returns back. This impedance does not influence the fault current if solidly grounded system is used. It affect the potential rise of non conducting metal parts during a fault.



In case of TN system the fault current flows through the metal enclosure, cable gland, Cable armour, cable tray, earthing conductors etc. The Earth Loop impedance will be the resultant impedance of several parallel paths Z1(earthing grid), Z2 (earthing conductors in cable tray), Z3 (cable tray), Z4 (Cable armour)



In case of TT and IT system the fault current flows from the metal enclosure to the earth at the load side and flow via the earth and then back to the source

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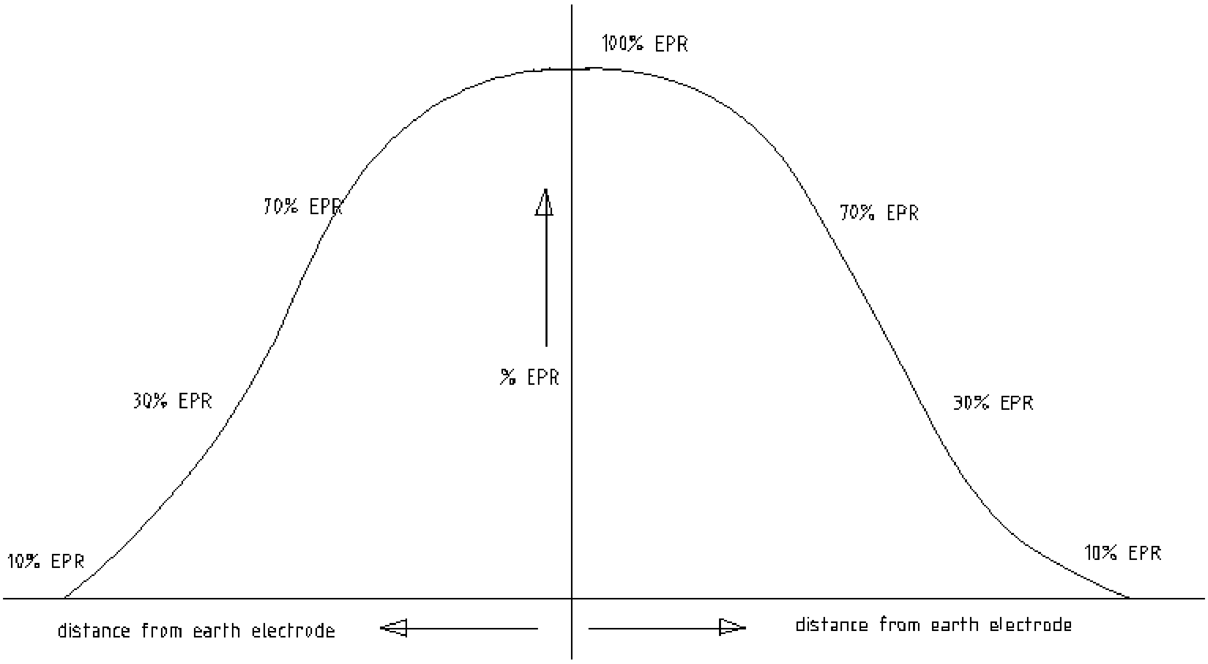
18.0 Potential gradient around the earth electrode

When a fault takes place some current flow through earth loop, some flow directly through earth and earthing terminal. The current which flows through the earth is the one which causes rise in the potential of the earth grid. The fraction of fault current that follows the earth path can be between 1 to 10%. For a 10KA fault it will be 100A to 1000A which flows through the earthing terminal. If the resistance of earthing system is maintained maximum 1 Ohm, the rise in potential can be in the range of 100V.This potential is high near the earthing terminal and falls as we move away from the earth terminal.



19.0 Earth Resistivity measurement

Earth resistivity can be measured by wenner four pin method. Two pins consist of current electrode and two pins consist of Voltage electrode. All four electrodes are equally spaced. More details about the method is covered in the standards. Users to refer them. The resistivity of the site gives an idea about the type of earthing system required. If earth resistivity is low upto 200Ωm or medium upto 400Ωm, the user need not worry much. But if earth resistivity is high in the order of 1000Ωm and if the area of the plot is small, to reduce the earth resistance special methods like chemical treated earth pits, deep bore earth terminals, Auxiliary ground mat may be required. Normally earth resistivity report will be available along with the soil test report.

20.0 Resistance of earthing system

The earthing system consisting of several earth electrodes and interconnecting horizontal conductors gives a earthing resistance which is much less than the resistance of single electrode. Different standards specify different values. Some standards don't specify any value. However it is a practise to achieve the resistance of the earthing system to be 1Ω.

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21.0 Measurement of electrode resistance

Earth resistance can be measured by different methods like fall of potential methods. The methods will be covered in a different guideline along with some practical site measurement examples.

22.0 What all needs to be earthed

All Non conducting Metal parts in a plant needs to be earthed. All the enclosures of various electrical equipment need to be earthed. Refer the Single line diagram of the plant, this gives an idea about all the electrical equipments used in the plant. All the equipments which needs to be earthed has to be shown in the earthing layout as shown in CL 23.0, CL 27.0, CL 34.0. Refer the table 7 for typical size of earthing conductor and what all needs to be earthed.

22.1 Source Neutral earthing

All Neutral of Generators, UPS, Transformers needs to be earthed. (Refer CL 15 for more details). Enclosures of UPS, Transformer and Generator are earthed separately but interconnected below earth.

22.2 Cable Armour earthing

The Main purpose of cable armour is to provide mechanical protection for the cable from external damages and also provide a tensile strength. Cable armour has a big advantage; it carries the fault current in case of fault in a cable or in case of fault at cable terminal. Fault develops inside a cable due to aging and this is due to one factor called water treeing. A tree like path is formed from the conductors of the cable to the outer surface of the cable. This path consists of tiny water particles which conduct electricity. If cable armour with earthing is provided, the water tree leads to a single line to ground fault which can be detected. If cable armour is not provided or earthing is not provided, it may lead to a Single line to ground fault which cannot be detected and subsequently it leads to line to line fault.The cable armour has to be earthed either at both the ends or at one end. If cable armour is earthed at both ends it may lead to circulating currents. In that case where there are high circulating currents, the cable needs to be derated. Capability of Cable armour to carry the fault current for certain duration should be verified. Armour of Single core cable should not be earthed at both the ends as it leads to high circulating currents. If unarmoured cable is used then a separate core with protective earth is required.

22.3 Cable Tray earthing

Cable tray are made of sections of some typical length like 3 meter. Each section tray is joined to the next section through metallic plates or through welding . Hence the entire cable tray is electrically continuous. Where the tray is discontinuous it needs to be connected to the next section through a cable. Some users have practise of running bare conductor or insulated conductor along the cable tray.

22.4 Electrical Panel and Distribution boards earthing

All Electrical panels and Distribution boards located indoor or outdoor needs to be earthed. The panels may be 415V or 3.3kV or 6.6kV or 11kV or 33kV . Panels are provided with a continuous earthing conductor inside the panel by the manufacturer. This conductor needs to be connected to the earthing system inside the electrical room. All electrical equipments

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inside switchgear room can be connected at one common place which can be connected to main earth grid located outdoor.

22.5 Junction Box earthing

Enclosure of Small JB used for lighting needs to be earthed if it is metallic. If JB are non metallic they should be earthed if provided with a metal plate inside. If Armoured control cables terminate at the metallic JB enclosure, then a metallic gland has to be used which will provide electrical continuity for the earthing.

22.6 Motor and Push button station earthing

Motor body has to be earthed directly to earth grid. Motor push button station (PBS) shall also be earthed. If the PBS enclosure is mounted on Metal frame, then the frame itself can be earthed near its footing or the PBS can be earthed directly.

22.7 Lighting poles and fixtures earthing

All Lighting fixtures shall receive three wires: phase, neutral and earth conductors from the junction box. Fixture earthing is carried out with the earth wire. The JB is earthed by one or all of the following: cable armour, earth wire connected directly to earth grid, earth wire connected to pole, if metallic JB is mounted on metallic poles it will be earthed by default. The Lighting pole shall be earthed directly to the earth grid.

22.8 Tanks, Vessels, Piping earthing

Non electrical metallic equipments like tanks, vessels, pipes etc which are process related also needs to be earthed to protect them from lightning strike and static charges. The metallic equipments shall be provided with earth terminal.

22.9 Package equipments earthing

All package equipments like Instrument air compressors, Chemical injection skids, Crane, Hoists etc should be earthed at two locations on the skid designated by the vendor. Earthing of various panels, motors, lighting etc within the package equipment internally shall be taken care by the manufacturer.

22.10 Lightning Protection system earthing

Lightning Protection system will have its own earth pits, horizontal conductors and vertical down conductors. LP earthing system needs to be interconnected with the main earth grid below ground. Detailed design about LP earthing system is given in a separate guide.

22.11 Electronic equipments earthing system

Electronic equipments are normally provided with separate earthing system. But same needs to be connected to the Power system earthing below earth. If this is not done, then there can be back flash into electronic earth during lightning and this can damage the insulation of the electronic equipment. Electronic earthing system can be completely isolated from other earthing system if its insulation can withstand voltage surge due to lightning. But this is not economical and practicable. Hence connecting both the system is required.

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22.12 Earthing of utility pipes

Water pipes or any utility pipes entering substation may be earthed or left unearthed depending on the local regulations. If it is earthed inside the substation, then the joint at the boundary of substation needs to be insulated to prevent transfer of potential from substation to outside. In Industrial site or building Water pipes shall not be used for earthing but it shall be bonded to the earthing system. Refer the local and national regulations before following standards and guidelines related to this clause.

22.13 Earthing of steel reinforced bars of structures and buildings

It is advantageous to earth the steel reinforced bars (rebars) embedded inside a concrete. The concrete has low earth resistivity and along with absorbed moisture and rebars, it acts as a low resistance earth electrode. When several such columns are interconnected to the earthing system they provide a good low resistance for the overall earthing system. Connecting rebars with earthing system also reduces the electrical noise interferences and EMC problems. During lightning strike there will be no back flash from earthing grid to concrete rebars if they are interconnected. However there are some disadvantages, the rebars will undergo corrosion due to some residual DC currents in the earthing system and during fault the current in rebars will cause heating, which will reduce the moisture in concrete. This can create cracks in the structure. Hence as per some regulations the rebars should not be connected to the earthing system. Hence refer to the local and national regulations before following any standards and guidelines related to this clause.

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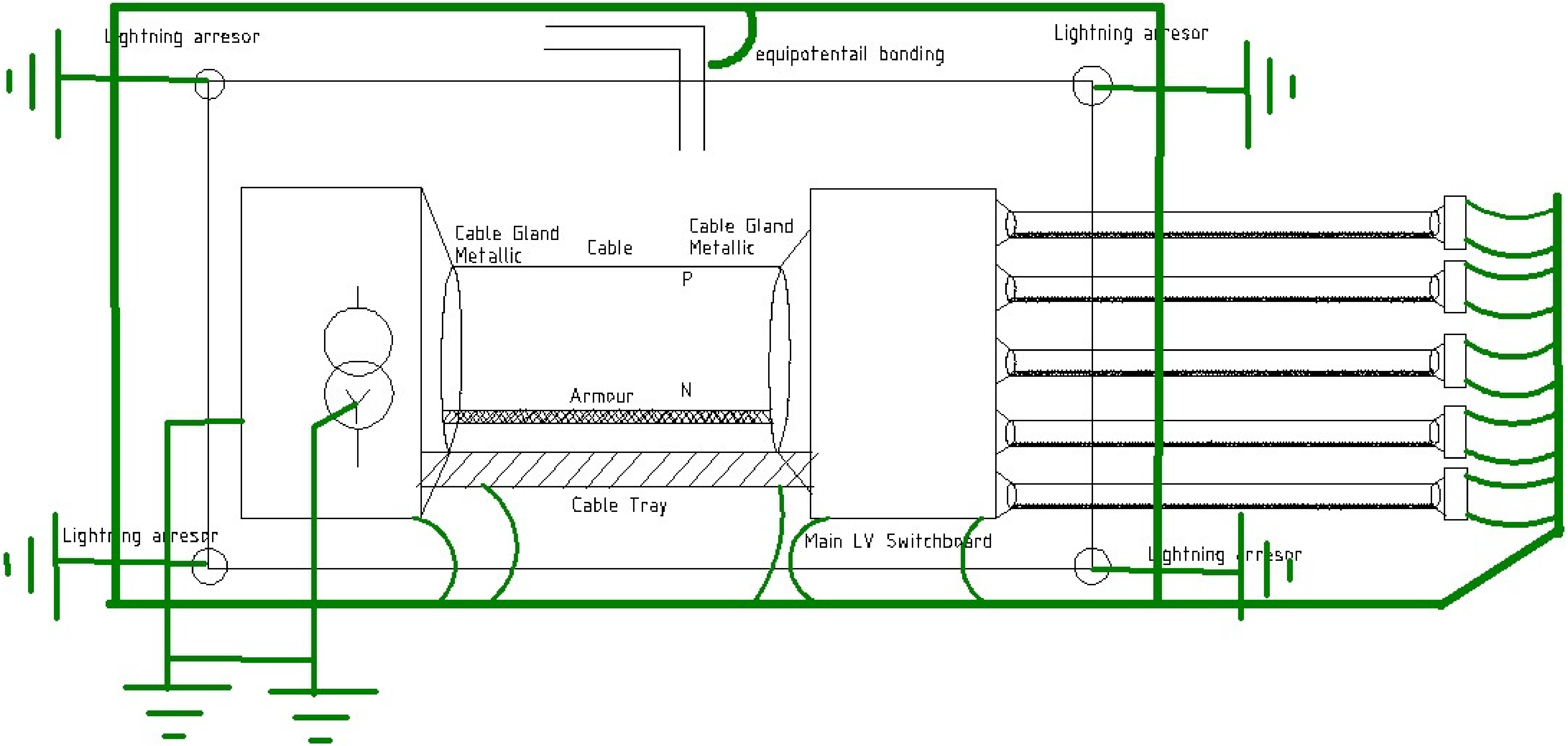
23.0 Earthing Schematic

Earthing schematic is similar to a layout but the representation is more symbolic than the actual layout. Similar to the layout it shows the earth pit/ earthing terminal, equipotential bonding conductors, horizontal earthing conductors. All Non conducting metal parts should be connected to the earth grid. For example Transformer body, Main LV Switchboard enclosure, Distribution board enclosure, Lightning protection system, metal pipes that enter the substation etc are connected to the earth grid via equipotential bonding. Before carrying out equipotential bonding with metal pipelines local regulations needs to be checked. For actual site installation Earthing Layouts with dimensions are to be used. The below schematic shows the earth path continuity from substation up to the end user equipment..



24.0 Types of Electrodes and their resistances

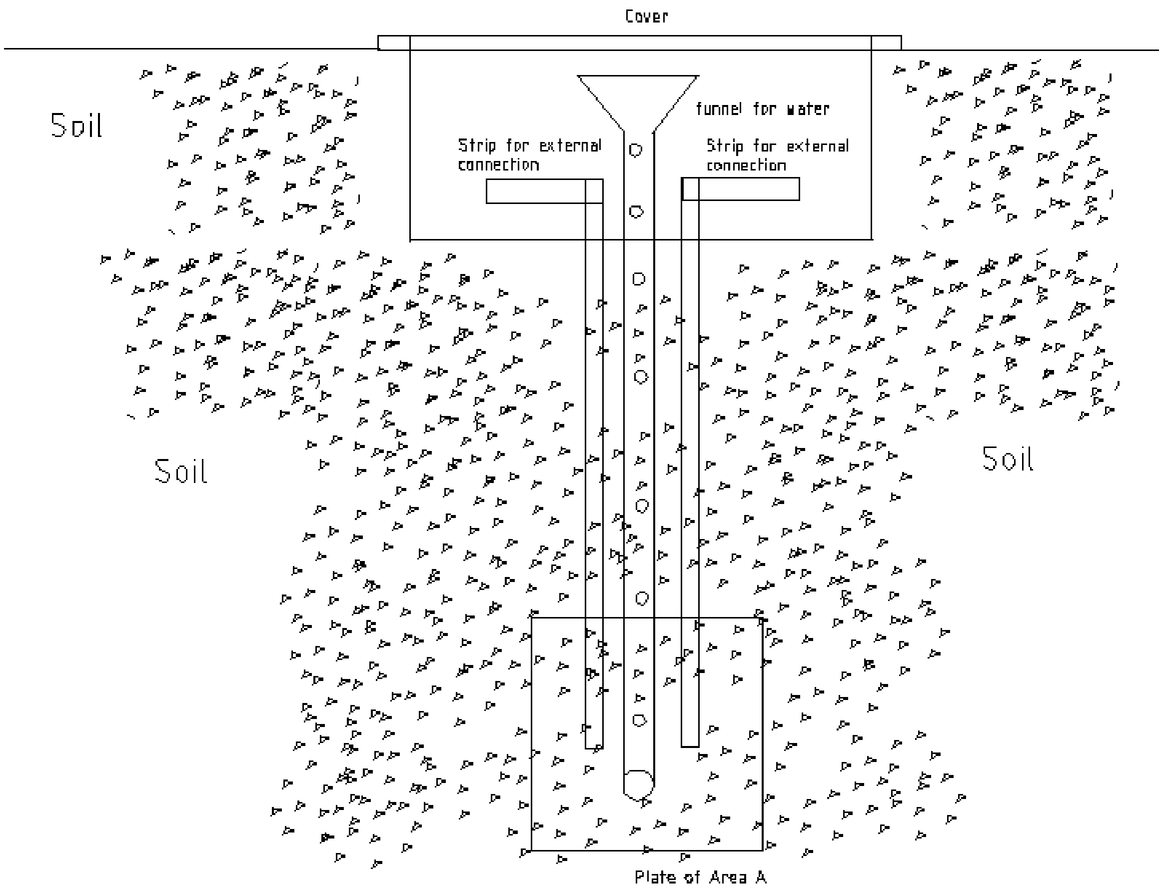
Different types of electrodes are: Plate, Pipe/Rod, Strip, Mesh. A given earthing system may consist of all of these or few of them. Normally strip electrode (Horizontal) and Rod electrode (vertical) will be used more often.

24.1 Resistance of Plate electrode

Plate electrode is used to earth the neutral of LV transformers due to large area of the plate.

R $=\frac{\rho}{4}\sqrt{\frac{\pi}{A}}$, ρ = resistivity of soil Ωm, A area of plate m^2 (BS 7430 CL 9.5.2, IS 3043 CL 9.2.1)

for example an earth pit with resistivity of 200 Ωm gives, R = $\frac{200}{4}\sqrt{\frac{\pi}{A}}$ = 125 Ω



The above drawing is only an illustration for understanding purpose. It should not be used as site installation drawing which is more detailed. (Drawing not part of BS 7430)

In the figure above, Soil surrounding the electrode is not treated with any chemical. Some users have the practise of adding salt and charcoal or some chemicals to reduce the resistivity. This again depends on the local regulations.

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24.2 Resistance of Rod or Pipe electrode

R = $\frac{\rho}{2\pi L}\left[\ln\frac{8L}{d} - 1\right]$ L length of rod m, d dia of rod m, Soil resistivity ρ Ωm (BS 7430, CL 9.5.3)

R = $\frac{\rho}{2\pi L}\left[\ln\frac{4L}{d}\right]$ (EN 50522, Annexure J)

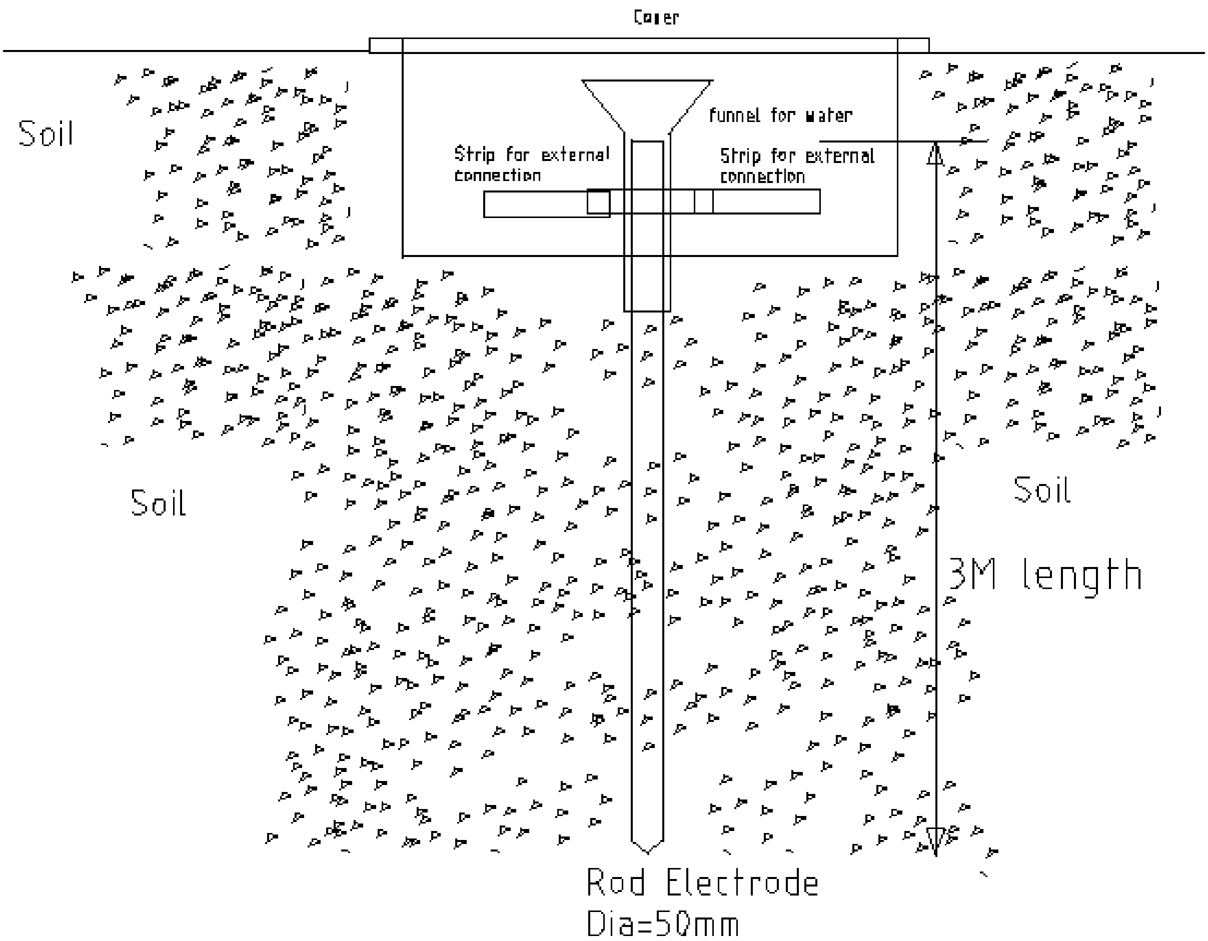
R = $\frac{\rho}{2\pi L}\left[\ln\frac{4L}{d} - 1\right]$ (IEEE 142, table 4-5)

R = $\frac{100\,\rho}{2\pi L}\left[\ln\frac{2L}{d}\right]$ L and d in cm, ρ Ωm (IS 3043, CL 9.2.2)

For ex resistivity of 200 Ωm, 3m length and 50mm dia rod gives, R = $\frac{200}{2\pi x3}\left[\ln\frac{8x3}{0.05} - 1\right]$ = 55 Ω

24.3 Resistance of Rod electrodes in parallel

R = $\frac{1}{n}\frac{\rho}{2\pi L}\left[\ln\frac{8L}{d} - 1 + \frac{L}{s}\ln\frac{1.78n}{2.718}\right]$ (BS 7430 Cl 9.5.4), n number of rods, s spacing between rods.



The above drawing is only an illustration for understanding purpose. It should not be used as site installation drawing which is more detailed. (Drawing not part of BS 7430). In the figure above, Soil surrounding is not treated with any other material.

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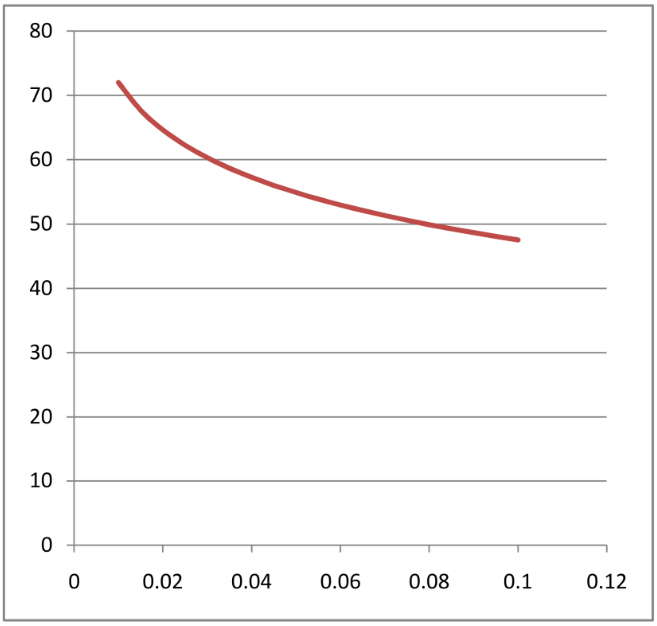
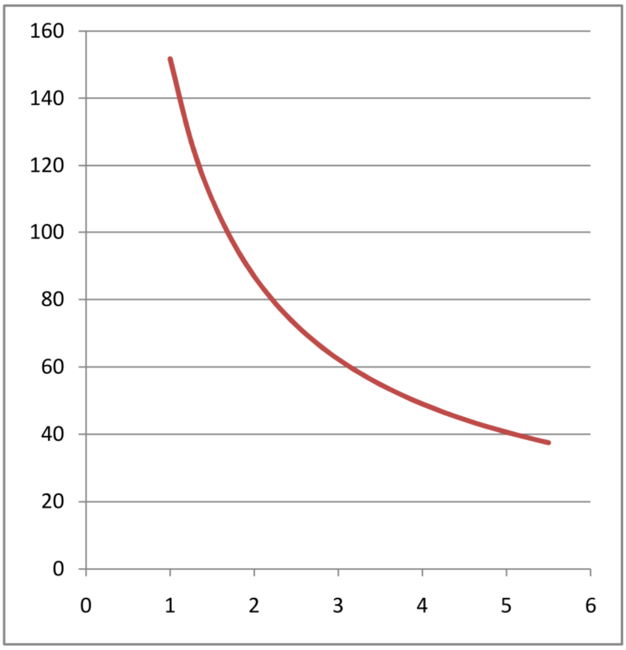
24.4 Variation of resistance of electrode due to length and diameter of the rod

(Table 5 and Table 6)

R (ohm)	L(m)	d(m)
71.97224	3	0.01
67.67012	3	0.015
64.61772	3	0.02
62.2501	3	0.025
60.3156	3	0.03
58.68001	3	0.035
57.2632	3	0.04
56.01349	3	0.045
54.89558	3	0.05
53.8843	3	0.055
52.96108	3	0.06
52.1118	3	0.065
51.32549	3	0.07
50.59346	3	0.075
49.90868	3	0.08
49.26543	3	0.085
48.65897	3	0.09
48.08529	3	0.095
47.54106	3	0.1



R(ohm)	L(m)	d(m)
151.7804	1	0.025
127.1066	1.25	0.025
109.7912	1.5	0.025
96.91057	1.75	0.025
86.92197	2	0.025
78.93026	2.25	0.025
72.37872	2.5	0.025
66.90205	2.75	0.025
62.2501	3	0.025
58.24558	3.25	0.025
54.75916	3.5	0.025
51.69418	3.75	0.025
48.97687	4	0.025
46.54994	4.25	0.025
44.36814	4.5	0.025
42.3953	4.75	0.025
40.60207	5	0.025
38.96446	5.25	0.025
37.46258	5.5	0.025



It can be seen that the resistance does not change much due to the diameter. A rod of 25mm or 50mm has very close values. Hence it is economical to use a rod of 30mm. Resistance changes more with length of the rod. Beyond certain length resistance does not reduce much. When length of rod doubles the resistance reduced by half, when diameter double the resistance reduced only by only 10%.

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24.5 Resistance of straight Strip

R = $\frac{\rho}{2\pi L}\left[\ln\frac{L^2}{1.85hd}\right]$, h is depth of electrode in m, L is length of strip, d is the diameter of round conductor or diameter of equivalent cross section area of the strip (BS 7430 CL 9.5.5)

R = $\frac{\rho}{\pi L}\left[\ln\frac{2L}{d}\right]$, d= half width of earth strip (EN 50522, Annexure J-2)

R = $\frac{100\rho}{2\pi L}\left[\ln\frac{4L}{t}\right]$, t= width of earth strip in cm (IS 3043 CL 9.2.3)

24.6 Resistance of Mesh

R=0.443 $\frac{\rho}{\sqrt{A}}+\frac{\rho}{L}$, A area of mesh m^2, L total length of conductor m (BS 7430 CL9.5.6)

R=$\frac{\rho}{2D}$ D is diameter of circle with same area as the mesh (EN 50522 Annexure J2)

24.7 Resistivity of electrodes encased in Low resistivity materials

R = $\frac{\rho_1}{2\pi L}\left[\ln\frac{4L}{d_1}-1\right]$ - $\frac{\rho_1}{2\pi L}\left[\ln\frac{4L}{d_2}-1\right]$ + $\frac{\rho_2}{2\pi L}\left[\ln\frac{4L}{d_2}-1\right]$

(IEEE Tran Industry and Gen appln Vol IGA-6,No 4, July/Aug 1970, Page 8)

d_1 dia of rod m, d_2 dia of encased soil, Soil resistivity ρ_1 Ωm, encased Soil resistivity ρ_2 Ωm

24.8 Earthing of steel reinforced concrete foundations

R_r=$\frac{1}{2\pi L}\left[(\rho_c-\rho)\ln\left(1+\frac{\delta}{z}\right)+\rho\ln\left(\frac{2L}{z}\right)\right]$ (BS 7430 CL 9.5.8.5)

ρ_c is resistivity of concrete in Ωm, δ is thickness of concrete between rods and soild in m, Z is geometric mean distance of rod clusters.

25.0 Treated earth electrodes

The resistance of earth electrode depends on the earth surrounding it. Earth is very large. Practically only few meters of earth around the electrode influences the resistance. As per IEEE 142 area close to 1 feet around the electrode influences 68% of the earth resistance. By adding Charcoal with salt, or Bentonite or mixing soil with salts like sodium chloride, calcium chloride, magnesium sulphate, copper sulphate or some other chemicals or by addition of some chemicals etc resistance can be reduced. Adding 5% salt in moisture will be very effective in reducing the resistance. Addition of materials around the soil leads to soil contamination and corrosion of electrode. Hence local regulations should be checked if addition of chemicals around the soil is allowed. These types of electrodes require regular monitoring and addition of moisture content. But at locations with very high resistivity it is very useful method to obtain low resistance earth electrodes.

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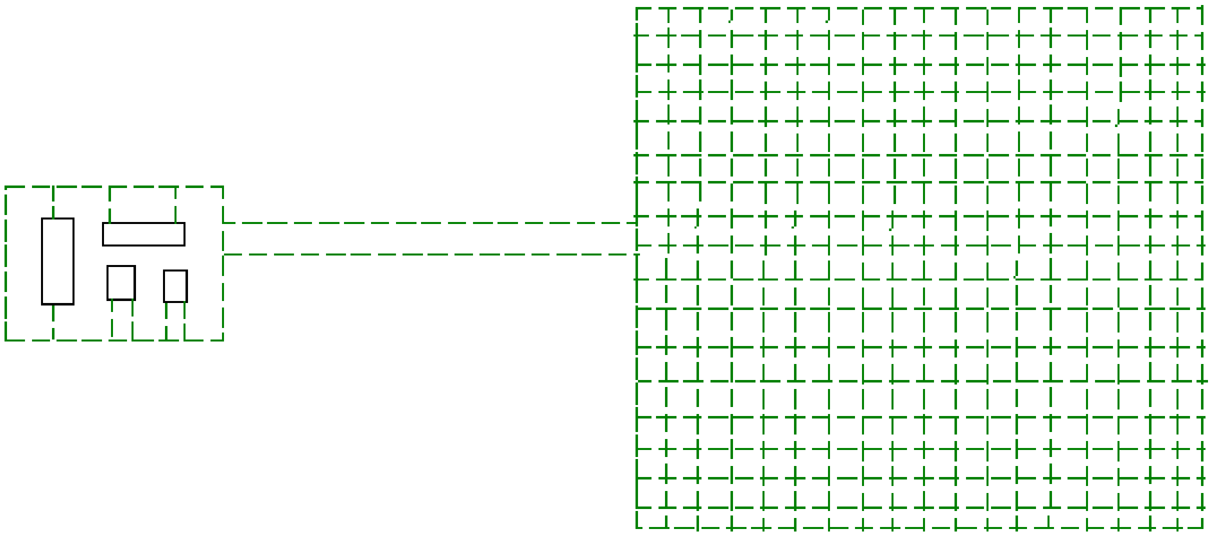
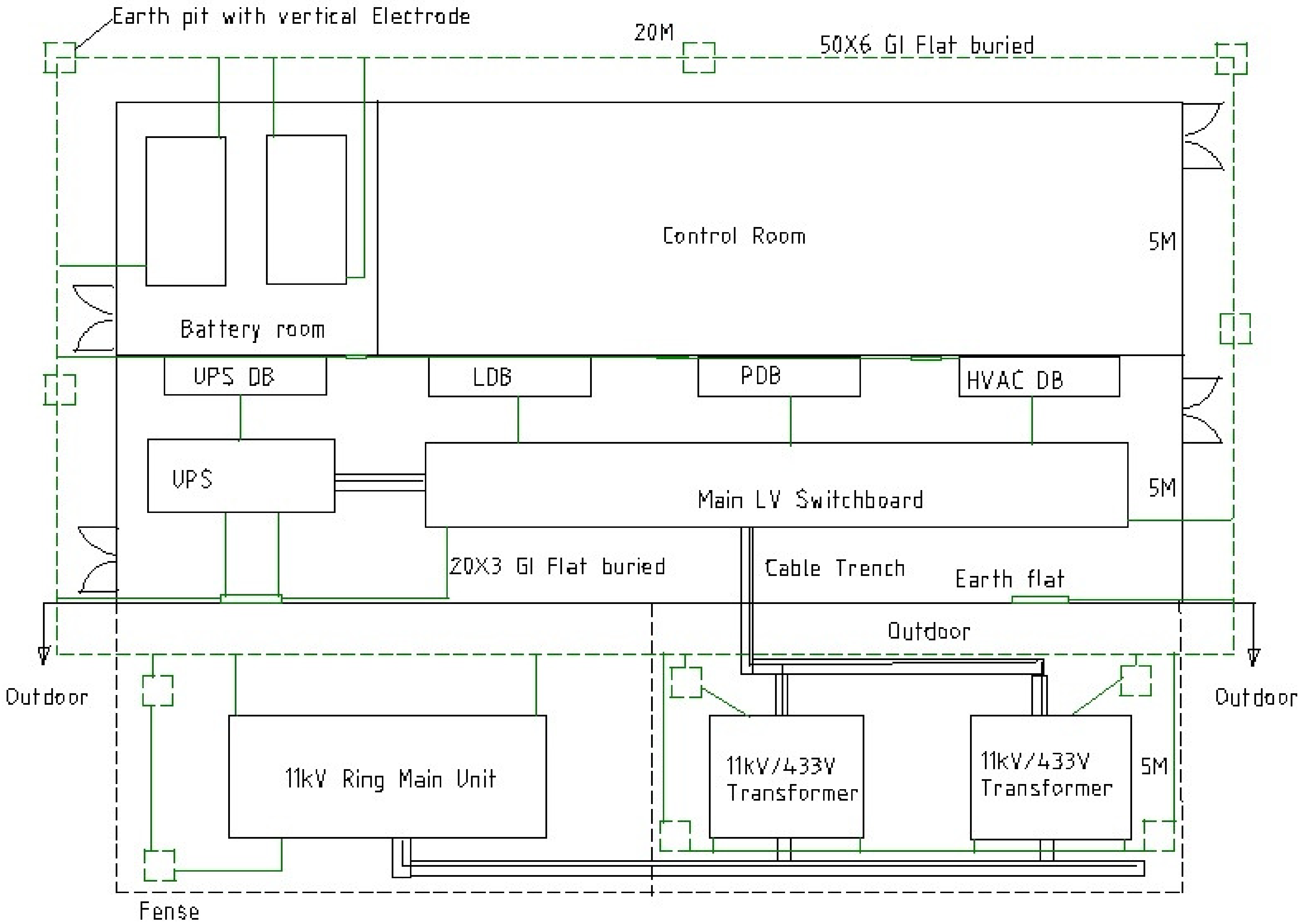
26.0 Auxiliary earth grid

A Separate earth mat/grid covering large area is designed and installed at some other remote location, this is connected to the plant or building earthing system which does not have large area to produce a low resistance earthing system. This design requires separate additional land which needs to be fenced to prevent access.



Auxiliary Earth grid

27.0 Typical Earthing Layout of LV MV Substations



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28.0 Layout Requirement

During the preparation of Earthing layout certain aspects like spacing between electrodes, depth of horizontal conductor, distance between building wall and electrode etc needs to be taken care. When horizontal electrodes are installed they should be surrounded by soil. They should not be surrounded by stones and gravels.

28.1 Spacing between electrodes

When several electrodes are used to reduce the overall resistance, ensure that space between each electrode is equal to depth of electrode or preferably twice the depth.

28.2 Distance between electrode and building wall

Maintain a clearance between electrode and building wall. This is required for proper excavation, maintenance, and to prevent back flash if building is not bonded

28.3 Depth of horizontal conductor or connecting conductors

Horizontal conductors connecting all the vertical driven electrode shall be laid below 0.5M from the ground level. The area surrounding this conductors should have soil. Lower depth will damage the conductors during construction, larger depth will lead to higher cost. In cold climates depth has to be high to escape the frozen soil.

29.0 Stray Currents

Currents are induced in earthing conductor due to a current flow in neighbouring conductors. This current create problem for communication. screening and separation can mitigate this.

30.0 Common mode noise

When there are third harmonics or unbalance currents in a system, it leads to a continuous current which will flow from the neutral to the earth. Due to this flow of current there is a small voltage drop from neutral to earth. This voltage may be around 2V, it is called common mode noise. This voltage may not cause safety hazard to people, but it creates interference and malfunction in electronic equipments. To mitigate it, third harmonics and unbalance problem has to be solved.

31.0 Typical Calculation of Earth electrode resistance of substation

Refer the typical substation layout shown above in CL 27.0. This consists of electrodes, straight run and mesh. Together the total resistance is calculated as given below.

31.1 Resistance of Rod electrodes in parallel (BS 7430)

$$R = \frac{1}{n}\frac{\rho}{2\pi L}\left[\ln\frac{8L}{d} - 1 + \frac{L}{S}\ln\frac{1.78n}{2.718}\right] = \frac{1}{11}\frac{200}{2\pi 3}\left[\ln\frac{8X3}{0.05} - 1 + \frac{3}{5}\ln\frac{1.78X11}{2.718}\right] = 5.8\Omega$$

31.2 Resistance of straight Strip (BS 7430)

$$R = \frac{\rho}{2\pi L}\left[\ln\frac{L^2}{1.85hd}\right] = \frac{200}{2\pi 20}\left[\ln\frac{20^2}{1.85X0.5X0.05}\right] = 14.4\Omega$$

31.3 Resistance of Mesh (BS 7430)

$$R = 0.443\frac{\rho}{\sqrt{A}} + \frac{\rho}{L} = 0.443\frac{200}{\sqrt{300}} + \frac{200}{70} = 7.96\Omega$$

Total resistance of the earthing system = 1/(1/5.8+1/14.4+1/7.96)=2.72Ω

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32.0 Type of joints

Different types of joints that can be used to connect one earthing conductor to another conductor are: Welding, exothermic, Brazing, Bolting etc. If may be preferred to do bolting at a petrochemical site to avoid fire. Brazing, welding, exothermic are stronger and the contact resistance will be much lower hence they should be used if there is no restriction in the site. Brazing, welding, exothermic joints can tolerate high temperature than bolting joints.

33.0 Recommended dimensions of earthing Conductor (Table 7)

	GS/GI mm	Copper wire mm^2
Tank	40X6 (flat),	70 to 185
Vessel	-do-	70 to 185
Vent	-do-	70 to 185
Flare	-do-	70 to 185
Piperack/Pipe sleeper(every 30M)	20X5(flat)	25
Pipelines	20X5(flat)	25 to 70
Motor push button station	Note, 6,8,10 mm^2	16
Lighting Junction box	Note 6, 10 mm^2	16
Motor	Note 3	Note 3
Light fixtures (integral with power cable)	Note 6	4 to 10
Lighting poles	16 to 25 mm^2	16 to 25
Transformer body	Note 1	Note 1
Generator body	Note 1	Note 1
Mechanical Package item	25mm^2, Note 1	25
UPS neutral	Note 1	Note 1
Generator Neutral	Note 1	Note 1
Transformer neutral	Note 1	Note 1
Pump house steel column	25 to 70 mm^2	25 to 70
Buildings	25X3 flat	25X3 flat
Cable tray	Note 1	Note 1
Cable trench	Note 1	Note 1
Main earth Grid	Note 1	Note 1
MV LV Switchgear	Note 1	Note 1

Note 1: Depends on SC calculation and sizing
Note 2: Above table is only for giving an idea, users to carry out calculation and refer the owner specification before choosing earthing conductor size
Note 3: Many owners specification provide earthing conductor size based on motor kW rating. It is better to choose the earthing cable size based on the actual short circuit level at the motor terminal. Motor located close to the switchgear may require bigger size earthing cable than recommend by owner's spec.
Note 4: GS Galvanised steel, GI Galvanised iron
Note 5: Cu or GI/GS can be used depending on owners choice.
Note 6: It is better to earth the push button station, junction box with copper cable, instead of GI wire as it will be difficult to connect the GI wire.
Note 7: insulated Cu wire is recommended for earthing of vessels, tanks and motors to avoid welding of. Lugs of the cable has to be tin coated
Note 8: Motor Push button station (PBS) if mounted on metal frame, earthing from PBS can be connected to the metal frame itself.
Normally the typical size mentioned in above table is furnished by the owner in their typical installation drawings. Same needs to be used. In case such drawings are not available, then this table can be referred.
Note 9: Using Solid GI wire(without strands) will have termination problem

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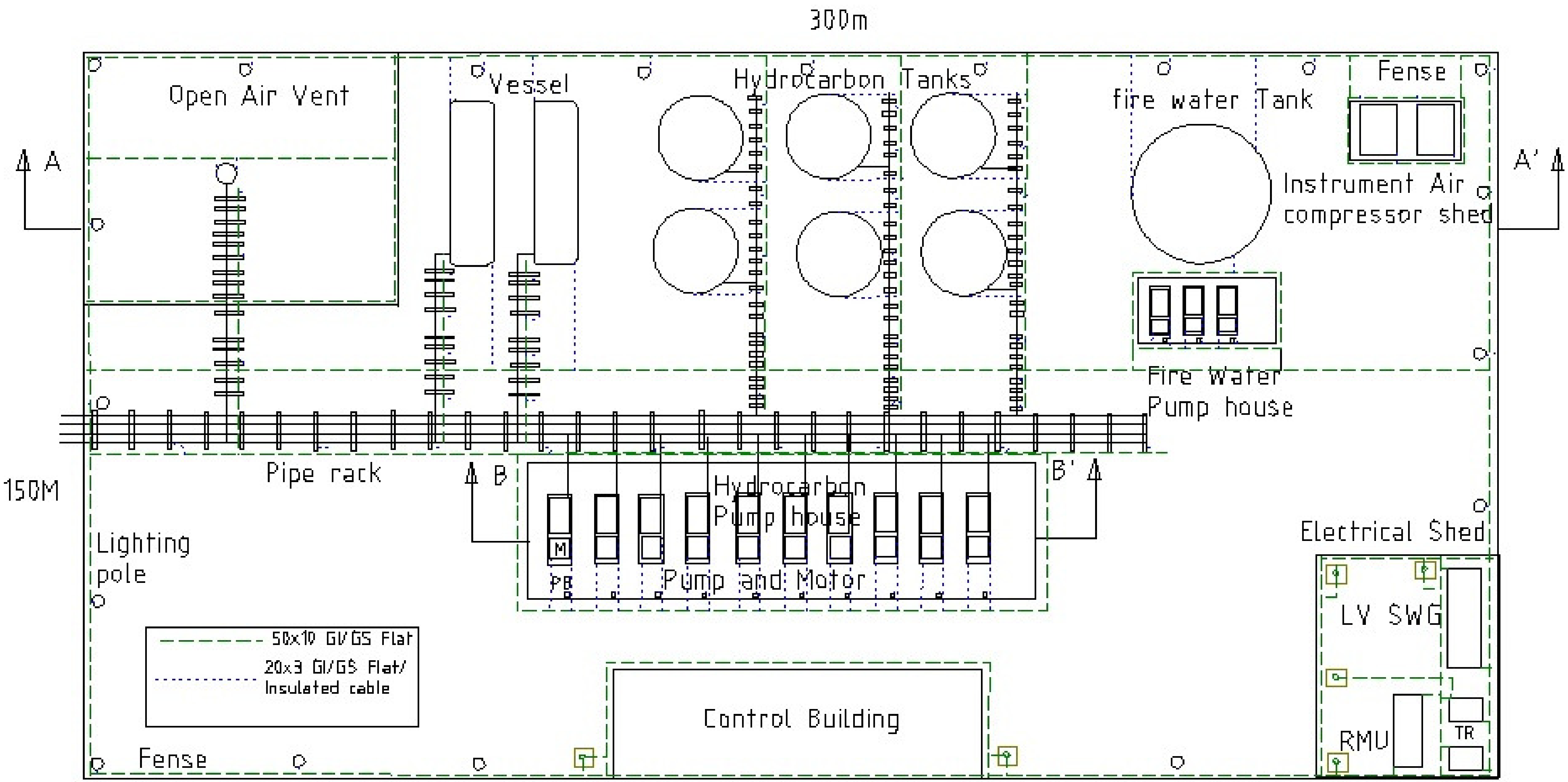
34.0 Typical Earthing design of Oil and Gas installation



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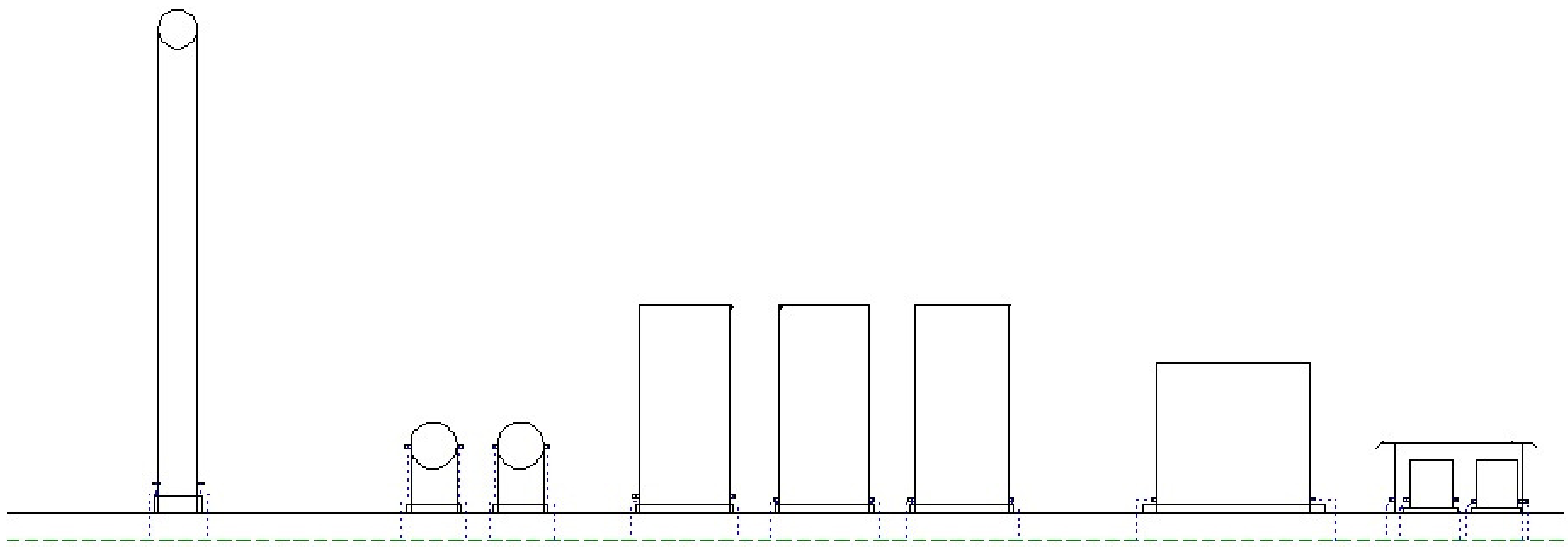
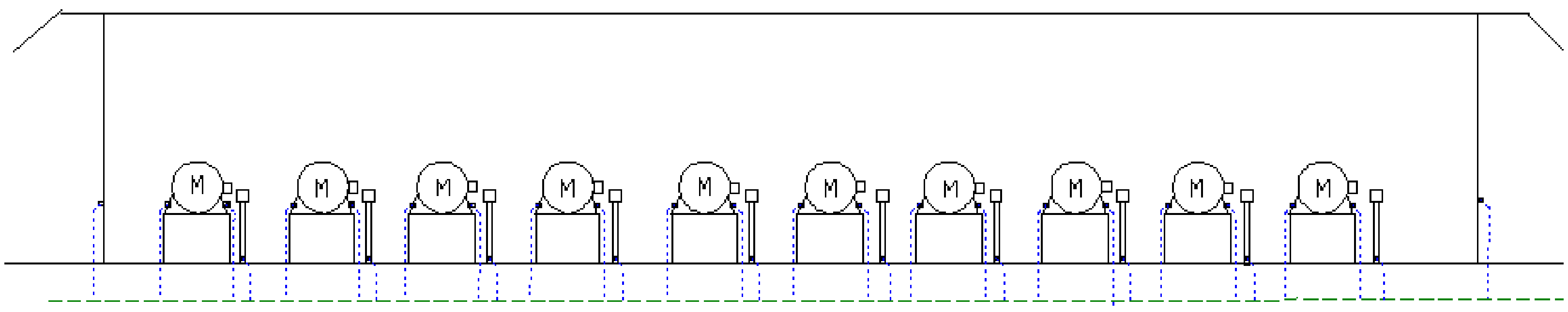


Sec AA'



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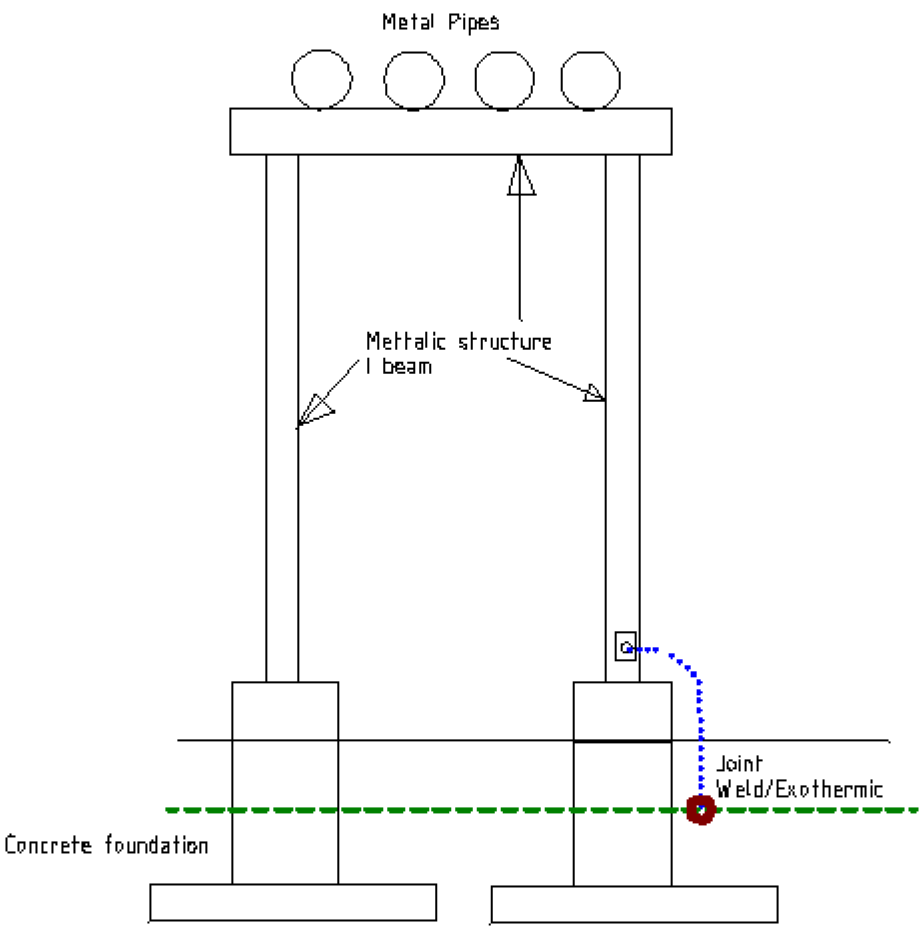

Piperack earthing

34.1 Calculation and steps for typical Oil and gas installation earthing design

The design shall be carried out by using the flow chart in CL 7.0

Step 1 Get Earth resistivity = 200ρm

Step 2 Get the plan layout as shown in CL 34.0, Here the area is big

Based on Step 1 (as resistivity is not >400) and Step 2 (as area is big), normal earthing design is sufficient.

Step 3 Select the conductor material

Area is having cathodic protection to protect the tanks, hence Cu is not preferred, for the main grid use GI/GS strip, for branch earthing conductors use GI or Cu. Refer table 8.

Step 4 Carry out sizing based on fault current

As per Short circuit study report fault level at 415V Main switchgear is 40KArms 1 sec. Fault level at terminal of motors varies from 10Karms 1 sec to 4kA depending of the distance. Size of branch conductor can be chosen from the earthing schedule. In some special cases where motor terminal fault location is high than expected, the branch conductor shall be sized. All Tanks, Vessels, Vent and pipe rack earthing is carried out to protect against lightning strike and static charge. Selection of the conductor size for lighting and static charge protection is not based on calculation, instead it is based on established practise by various owner's specifications and guidelines.

Sizing of main conductor (GI/GS) (for area around switchgear):

$S = \frac{I\sqrt{t}}{k} = \frac{40000\sqrt{1}}{55.5}$ =720mm2 ,

Taking 20% margin for corrosion = 720X1.2= 860 mm2,

Consider two runs for 50X10 GI flat or 35mm dia rod. Cu cable can also be used

Sizing of conductor (GI/GS) for area in the plant:

$S = \frac{I\sqrt{t}}{k} = \frac{10000\sqrt{1}}{55.5}$ =180mm2,

Taking 20% margin for corrosion = 180X1.2= 216 mm2

Consider 40X6mm GI flat. Cu cable can also be used

Sizing of conductor connecting motor, pump, tanks and vessels to earth grid:

Consider 40X6mm GI flat or Cu wire insulated as per schedule.

Step 5 Verify the resistance of the horizontal earth strip using CL 24.5, determine required number of vertical driven rods and the overall earth grid resistance.

Resistance of horizontal earth strip

Area of conductor for plant area is 216mm2, equivalent dia is 16.6mm

$R = \frac{\rho}{2\pi L}\left[\ln\frac{L^2}{1.85hd}\right] = \frac{200}{2\pi\, 1200}\left[\ln\frac{1200^2}{1.85\, x\, 0.5\, x\, 0.0166}\right]$ =0.49 ohm (this is below 1 ohm)

There is no further requirement of vertical driven earthing rods, however four driven vertical electrode are used inside the area around the electrical switchgear and transformer. Two vertical electrodes are used near the control building.

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Step 6 using the layout and the conductors sized in above steps determine the total length of all conductors and make a schedule as given in table 8. This is called Bill of material (BOM) or Bill of quantity (BOQ) or other names depending on the organisation.

This list is given to the procurement department who will use this list to order the earthing materials.

SL No	Item used for earthing of	Item Description (Option1)(Iron)	Item Description (Option2)(Insulated Cooper) green colour	Item Description (Option3)(Mixed)	Quantity
1	Electrical panel and transformer	50X10 GI Flat X 2 runs	1CX300mm^2	50X10 GI Flat	100m
2	Main conductor in plant area	40X6 GI flat	1CX185mm^2	40X6 GI flat	1800
3	tank, vessel, vent	40X6 GI flat	1CX70mm^2	1CX70mm^2 (Insulated Cu)	50m
4	Connectors for item 3	NA (weld)	Lugs tin coated for 70 mm^2Cu cable	Lugs tin coated for 70 mm^2 Cu cable	50 nos
5	Motor/Pumps	40X6 GI flat	1CX70mm^2	1CX70sqmm (Insulated Cu)	100 nos
6	Connectors for item 5	NA (weld)	Lugs tin coated for 70mm^2 Cu cable	Lugs tin coated for 70mm^2Cu cable	100
7	lighting poles	10mm OD GI wire	1CX16mm^2	1CX16mm^2 (Insulated Cu)	50m
8	Connectors for item 7	NA	Lugs tin coated for 16mm^2 Cu cable	Lugs tin coated for 16mm^2 Cu cable	20 nos
9	Junction box, Push button stations	10mm OD GI wire	1CX16mm^2	1CX16mm^2 (Insulated Cu)	50m
10	Connectors for item 9	NA	Lugs tin coated for 16mm^2 Cu cable	Lugs tin coated for 16mm^2 Cu cable	20 nos
11	Pipe rack	20X5 GI flat	1CX25mm^2	1CX25mm^2 (Insulated Cu)	20m
12	Connectors for item 10	NA	Lugs tin coated for 25mm^2 Cu cable	Lugs tin coated for 25mm^2 Cu cable	40nos

Table 8

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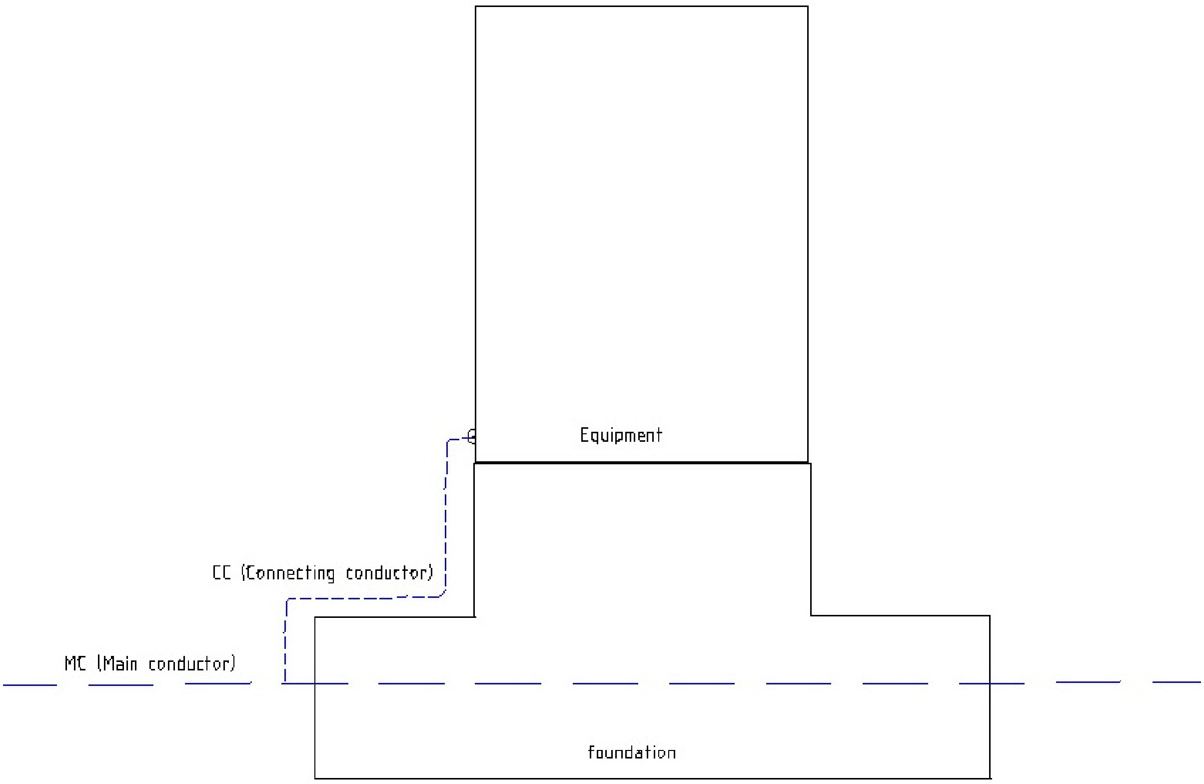
Main conductor (MC), connecting conductor (CC) can be of several different materials as shown below. This depends on the individual owners specifications.

MC	CC	remarks
GIF	GIF	EIL standard
GIF	ICSW	
GIF	GSEW/GSSW	SAIL standard
GIF	GIWS	
MSR	GIF/GSEW/GSSW/ ICSW	Rarely used MSR used mainly for big substation.
BCF	ICSW	
BCR	ICSW	Rarely used
BCW	ICSW	Rarely used
ICSW	ICSW	Shell standard. Horizontal conductor cannot be taken for earth resistance. Several vertical driven rods need to be used to achieve low resistance of the earth grid.

Table 9

GIF- Galvanised iron flat, MSR-Mild steel rod, BCF-Bare copper flat, BCR-Bare copper rod, BCW-Bare copper wire, ICSW-Insulated copper stranded wire, GSEW-Galvanised steel earth wire, GSSW-Galvanised steel stranded wire, GIWS-galvanised iron wire stranded.



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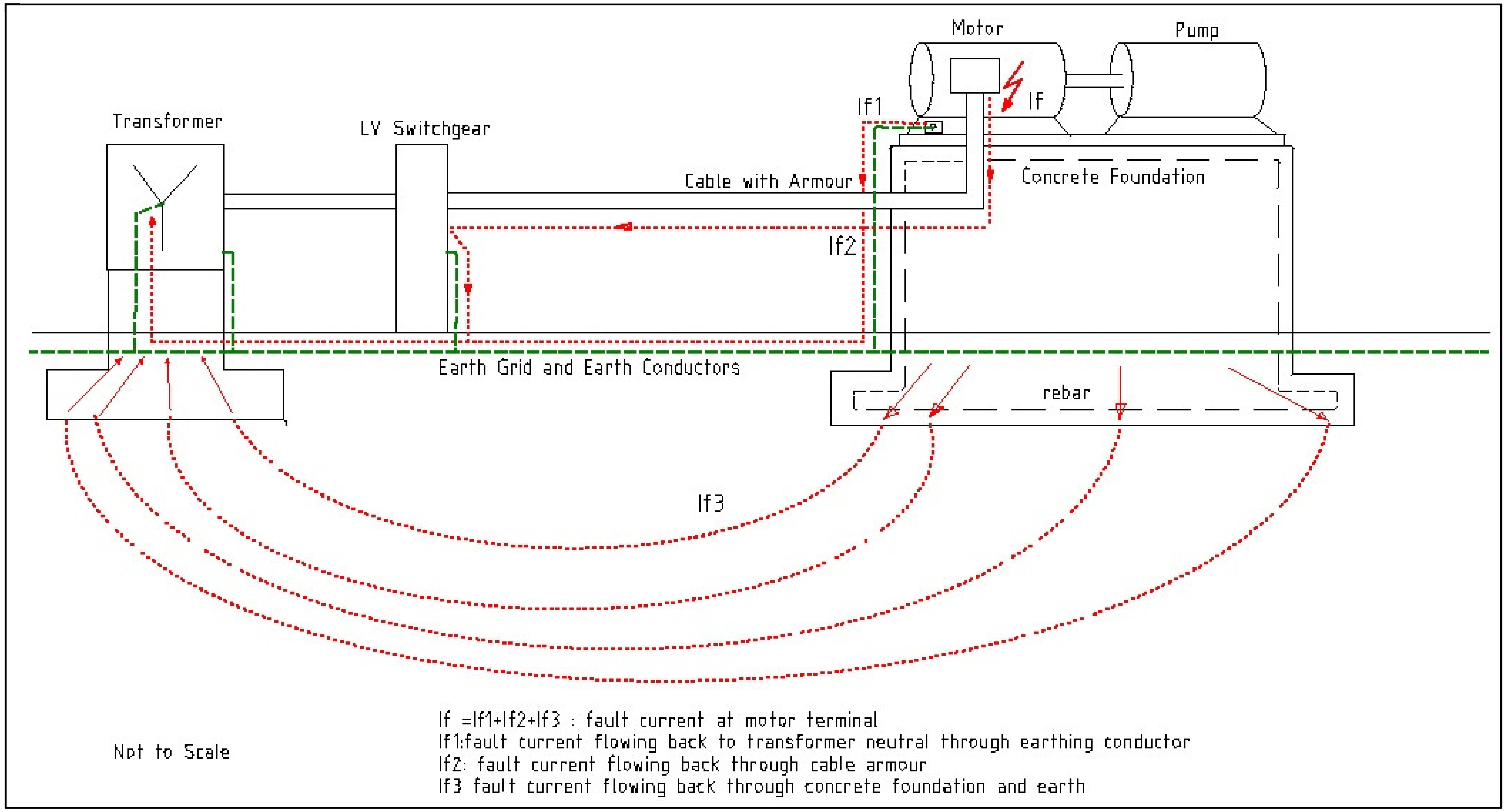

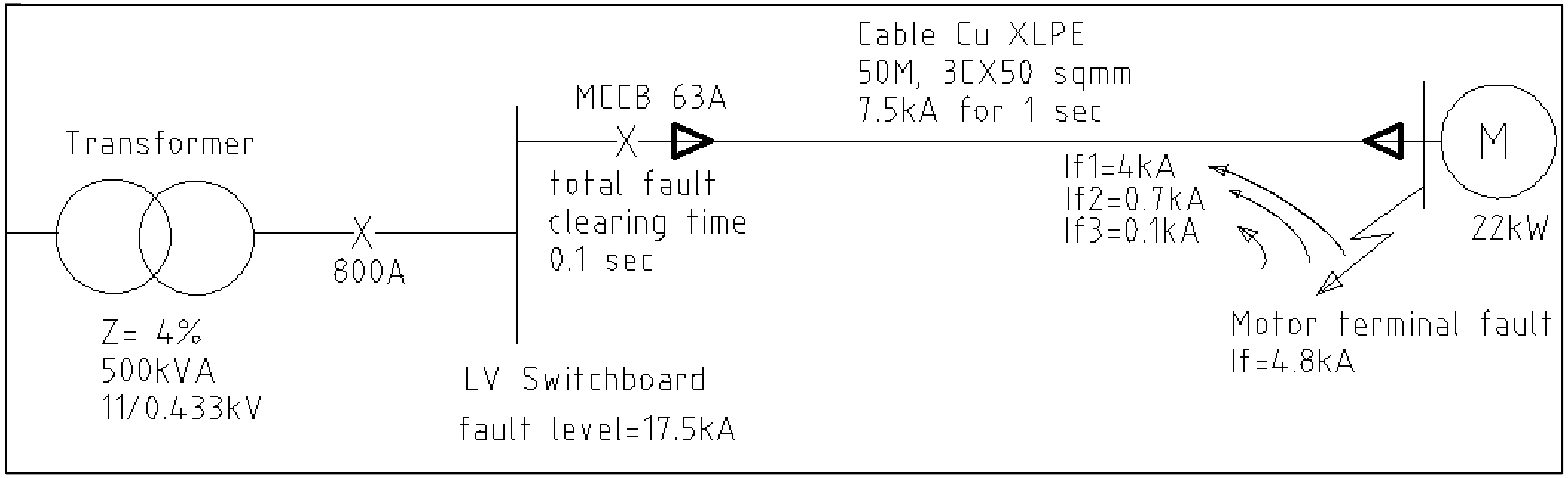

The fault current flowing through the earthing conductor connected to the motor is 4kA.

If the motor is earthed through 25sqmm Cu cable as suggested by earthing schedule provided by owners specification, the earthing cable will be insufficient. The cable required is 35sqmm or 50sqmm.

When motor are close to the switchgear following the earthing schedule without verification is not good. It is better to verify the sizing of earthing conductor as explained below

Short Circuit Current calculation for fault at Motor terminal and Earthing conductor sizing.

50mm^2cable impedance= 0.8 mΩ/m

Total impedance=0.8 mΩX50m= 0.04Ω

Base impedance=0.4X0.4/0.5= 0.32Ω

PU cable Z=0.04/0.32=1/8=12.5%

Ztransf+Zcable=4%+12.5%= 16.5%

1/Z=1/0.165=6.06

Base current =500kVA/(1.732X0.4kV)=721A

Fault current at Motor terminal=6.06X721=4373AX1.1= 4.8kA.

The earthing conductor shall be suitable to carry 4.8kA for 1 sec, Though fault clearing time is 0.1 sec earth conductor shall be sized for 1sec. hence select 1CX35mm^2 or 1CX50mm^2 Cu cable.

No 213, 13th Main RBI Layout JP Nagar 7th Phase, Bangalore 560078., Mobile: 91-9880784082, Email: vkes@vkes.org, vkes765@gmail.com, www.vkes.org

35.0 Reference

- BS 7430: Code of practise of earthing
- IEEE 142: IEEE recommended practise of grounding of industrial and commercial power systems
- EN 50522: Earthing of power installations exceeding 1 kV a.c
- IS 3043: Code of practise for earthing
- IEEE Transaction Industry and General application Vol IGA-6,No 4, July/Aug 1970

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Email: vkes@vkes.org, vkes765@gmail.com, www.vkes.org

ABOUT VKES

Vidyuth Kanti Engineering Services is a Bangalore based Startup by Paneendra Kumar BL.

Paneendra Kumar BL is a Charted Engineer (UK), Senior member IEEE (USA) , Associate member institute of engineers India.

He has done Masters in power system from IIT Delhi and BE Electrical from RV college of engineering Bangalore.

He has 15 years experience in Electrical Engineering of Transmission and Distribution, Industrial power distribution, Power plants, Oil and gas installations and Power quality.

He has published papers in International journals. He is also part of few standards development.

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Mob: 9880784082

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